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Review of (U-Th)/He Geothermochronology: Technique and Application

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Abstract: The application of (U-Th)/He dating to establishing tectonic histories started with the pioneering work (Zeitler, 1987), since the suggestion that (U-Th)/He ages of apatite might function as a huge potential thermochronometry tools used to resolve the thermal history of rocks in the upper kilometers of the Earth's crust, many He diffusion kinetics advances have been made in a variety of minerals, Apatite, zircon and titanite are the three most widely candidates minerals in (U-Th)/He dating. These advances include the helium diffusion characteristics and closure temperature (Tc)，Helium Partial Retention Zone (HePRZ) (Shuster et al., 2006;Stockli et al.,2004);zircon and monazite small U-Th-rich inclusions (Farley et al.,2002); zircon zoning compositional influences, crystallographic defects and radiation damage (Hourigan et al.,2005), andthe alpha-ejection process (Farley et al.,2002).

(U-Th)/He dating has drawn much more attentions in geologic applications, largely because of its uniquely low closure temperature. More recent efforts confirm variety of minerals approximate closure temperature.

The (U-Th)/He system in apatite (AHe) is widely used as a thermochronometry because of its ubiquity and moderately high U and Th content, more importantly because He accumulation in apatite occurs at even lower temperatures below 70℃than the apatite fission track method. Apatite (U-Th)/He dating has been used to study tectonic processes that cause latest stages of cooling in the uppermost crust. Several studies have attempted to interpret apatite (U-Th)/He ages from cratons should be paid to diffusion anomalous He retention in apatite in different apatite species(Green et al., 2006). Apatite (U-Th)/He dating is now a well-established thermochronology technique and is widely applied across a range of tectonic and surface processes，such as tectonothermal evolution in sedimentary basins (Chang et al.,2012;Qiu et al., 2011); landscape evolution (Riffel et al., 2015); the river incision (Shen et al., 2016), the ore deposits erosion and preservation history(Feng et al.,2017).

Some reseaches presented results of zircon (U-Th)/He ZHe ages from lunar impact breccia to detect low-temperature or short-lived impact events (Kelly et al., 2018).Other studies about zircon He ages include measuring eruption ages for volcanic rocks (Li et al., 2014)**,** revealing a multi-episode cooling history of the Baogutu porphyry Cu deposit, and zircon (U-Th)/He dating used to constrain t-T paths of metamorphic units (Maino et al, 2012). (U-Th)/He dating of zircon as young as ca. 2.5 ka has provided a new approach suitable for dating Quaternary science and tephrochronology(Martin et al., 2017). A number of studies reported zircon He ages from a wide variety of locationsand tectonic settings.

Fruitful achievements on（U-Th）/He dating were obtained in the past few years.The (U-Th）/He dating has potential as a dating metasomatic fluid events for diamond. Thepresent study providesfirst evidencethat some fibrous diamonds can be formed in 10s to 100s Myr before the kimberlite eruption (Timmerman et al., 2019).

Increasingly research provide compelling evidence that He diffusion characteristics for most minerals so far investigated. As He can be lost through thermally-activated volume diffusion, a (U-Th)/He age may record either sub-closure temperature crystallization or cooling through its thermal sensitivity window. Other accessory and rock forming minerals, such as rutile, monazite, and titanite have also been investigated and used as potential thermochronometries.

Cooperdock (2018) suggest that magmatic spinel was an attractive mineral for He dating as it is commonly free of U-Th-bearing inclusions and is a ubiquitous rock-forming phase in ultramafic rocks. These study results demonstrate that magmatic spinel (U-Th)/He dating may be used to determine the cooling age of oceanic lithosphere in magma-starved margins.

The common phosphate minerals such as xenotime and monazite have found widespread use in (U-Th)/He Dating. Monazite have reported highly variable He diffusivity and composition can significantly affect He diffusion parameters. High concentrations of Th and U in monazite ensure that 4He concentrations can be readily measured, even for Late Cenozoic monazite (Peterman et al., 2014)**.**

Boyce et al. (2005) presented the results of He diffusivity experiments, suggesting 180-290℃ closure temperature for monazite. Previous studies of natural examples have shown that xenotime is an U-Th-Pbisotopically robust chronometer, but xenotime have caused far less attention for He dating than apatite and monazite. Rutile is a primary accessory mineral in a variety of HT and HP metamorphic rocks and some plutonic rocks. Stockli (2007) showed rutile closure temperature of 220-235°C from mantle and lower-crustal xenoliths. It can offers the possibility of quantifying an important portion of the thermal history in metamorphic rocks.

In addition, there is other minerals for He thermochronometry, Fe-oxide minerals and manganese oxides, such as magnetite and hematite. Previous thermochronometric studies have utilized

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mafic volcanic rocks (U-Th)/He data to demonstrate yielding a well-behaved Arrhenius relationship and a closure temperature of ~ 250 °C. It will be a potential thermochronometry for an alternative volcanic geochronology (Blackburn et al.,2007). Hematite is commonly found in fault zones, Lippolt and coworkers have undertaken detailed studies of hematite He diffusion in each sample to estimate approximate closure temperatures from 140 to 240 °C(Lippolt et al.,1993; Evenson et al., 2014). Reiners and Farley (1999) based on laboratory stepped -heating experiments concluded that titaniteHe closure temperature is in the range 191 to 218°C.

(U-Th)/He dating analytical techniques have fast been developed, including mineral separation, sample air-abrasion to correct for α-ejection effects and so on. The future of (U-Th)/He geochronology is bright. Intense interest in understanding near-surface processes and links between tectonics, erosion, and climate will continue to motivate advances. New suitable minerals are being developed that will expand accessible temperature ranges, eg. crinoid fossils (Copeland et al.,2015).

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